FLOODS IN THE DESERT - HEAVY RAINS IN THE DRY REGIONS OF WESTERN AUSTRALIA

By J. GENTILLI
Department of Geography, University of Western Australia, Nedlands 6009

LIMITS, AIMS AND METHODOLOGY

The immense dry areas of Western Australia have only one general and well-known climatic characteristic in common, the scarcity and skewed distribution of their precipitation. Briefly, the distribution is strongly skewed because in every locality there are long periods with no rainfall at all, other periods with very little rain, and occasional days with very heavy downpours. In all other respects various parts of these dry areas (climatic subregions) have characteristics of their own, be they the diurnal and/or seasonal incidence of the scanty precipitation, the mode and intensity of its falls, the regime of daily and seasonal temperatures, the overall monthly, seasonal or annual moisture balance (Gentilli 1972). Regional slope and relief and local soils and landforms have a strong influence on the flow and storage of fallen rainwater, at times considerably extending the availability of moisture in space and time.

In an arid environment, even the smallest amount of moisture can be very significant: there is real need of a study of the incidence and biological roles of dew, particularly near the western and northern margins of the desert. However, this paper is only concerned with heavy falls of rain, which are likely to cause some surface run-off, stream or even sheet flow, deep infiltration and local flooding. Dew and light rain keep alive plants and animals living on or near the surface, but heavy rains soak the soil, flood streambeds and lakes, and awaken seeds, eggs and individuals dormant well below the surface.

For practical reasons, heavy rains have been defined here as those amounting to at least 100 mm in one month, implying heavy falls, mostly of great intensity, within only a few wet days. A rare error by default would occur if, say, a cyclone brought over 100 mm of rain divided between two successive months, neither of which might be counted.

Figure 1 shows the position and names of the main rainfall stations used. If a station's record was incomplete, it was supplemented with

Figure 1. Rainfall stations used, 300 and 600 m contours, rivers, main lakes (L) and boundaries of drainage regions.

the record of a station near by. This was not possible in the case of some outlying stations, e.g. Glen Ayle, Earaheedy and Lorna Glen. The contours of 300 and 600 metres are shown with dotted lines; they are particularly important in the Pilbara Region, where to a great extent they guide the drainage pattern.

The great drainage regions are shown by dashed lines. The largest one (A, broadly corresponding to the Australian Water Resources Council's 'Indian Ocean' Region) occupies the Pilbara Region plus the Murchison and Greenough catchments. It drains outwards [exoreic drainage, *cf* Gentilli 1952b] to the Indian Ocean, but its surface drainage is only occasional, depending on heavy showers from tropical cyclones in the hotter months and variable rain from epitropical cloud bands in the cooler months. The duration of run-off ranges from momentary on the upper slopes to almost permanent below the sediments on the main valley floor. Towards the south-west this region almost encloses a small subregion (B) with no surface drainage, between the Gascoyne and Murchison catchments and the coast near Shark Bay. The lower tracts of the Murchison and Greenough rivers (C) have a more reliable, seasonal drainage fed with rainwater by the extreme northward reach of mid-latitude frontal depressions (not studied here).

The remainder of the area shown in Figure 1 corresponds approximately to the Australian Water Resources Council's 'Western Plateau' drainage region, but shows interesting subdivisions. Its southernmost subregion (D) belongs to Woolnough's 'Salinaland' (Clarke 1926); it has a multitude of salt 'lakes' more like dry river beds, or dry confluences of rivers, some of which after very heavy rains may still occasionally overflow in a coordinated saline drainage pattern (cf van de Graaff *et al.*, 1977) to reach the coast further south. Its central subregion (E) has few relict 'lakes' and stream beds and vast expanses of dunes; such surface drainage as may occur after rare cyclones remains inland [areic drainage] and is truly ephemeral. Its northern subregion (F) corresponds to the Canning Basin and has no surface drainage at all, except for relict traces of a much wetter climatic phase (Wyrwoll *et al.*, 1986), along the subregion's north-eastern margin, just outside the area shown in the map.

THREE BASIC MECHANISMS: CYCLONE, NORTHWESTERLY FLOW AND PSEUDO-MONSOON

Years ago it was suggested that a systematic and gradual series of studies of bioclimatic conditions in Western Australia was needed (Gentilli 1948, 1951). With regard to the contribution of heavy downpours to the arid regions of Western Australia three very different weather mechanisms are at play, namely tropical cyclones, monsoons and north-westerly epitropical flows. It should be noted that they all convey water from the sub-equatorial to the tropical latitudes. Their warm air can hold large amounts of water, hence the great intensity of the falls of rain they unload. Thunderstorms may also uplift large amounts of moisture locally, but the moisture that 'feeds' them can only be brought by the mechanisms already mentioned.

Towards their southern margins the arid regions receive 'winter' (more correctly, cool-semester) rains from weather fronts associated with mid-latitude depressions, but the intensity of the individual falls of rain and the monthly totals are quite moderate and would not normally come within the scope of this study. Rare heavy falls (apart from local thunderstorms) are brought by stray cyclones or unusually deep northwesterly flows, and once or twice in a century (e.g. in February 1955) by very exceptional monsoonal transgressions.

The spatial pattern of heavy episodic falls of rain due to tropical cyclones crossing normally dry land was studied and mapped (Gentilli 1961), with the gratifying sequel that from 1964-65 onwards tropical cyclones were regularly reviewed by the Bureau of Meteorology (1968 ff.). Lower ocean surface temperatures normally preclude massive evaporation and the formation of tropical cyclones off the west coasts of other continents; Western Australia is unique in this respect (Gentilli 1972a, 1991). The mean monthly rainfall brought by tropical cyclones, its percentage proportion of the monthly mean total rainfall, and the 10-year and 20-year probable amounts in 24 hours and probable monthly totals have been mapped by Milton (1978).

The term 'pseudo-monsoon' was first used when referring to monsoonal phenomena in Western Australia (Gentilli 1971, p. 84) because even at the peak of the monsoon season in January the average flow of air into the Kimberleys comes from the west or west-southwest, being shallow 'recycled' air from subtropical anticyclones. A recent detailed map of January resultant surface winds by Ramage (1984, p. 622) confirms even more forcefully that the air that flows into the Kimberleys normally comes from the eastern edge of the Indian Ocean anticyclone, starting only a short distance offshore from the Perth coastline. The normal lack of a trans-equatorial connection in the westerly air flow into the Kimberleys was also confirmed by a later study of cloud formations by Matsumoto (1989). This peculiar weakness of the Australian monsoon explains why incursions of truly monsoonal air over the dry interior are so rare. The greatly strengthened southerly flow along the west coast across latitudes 30 and 29 S. accounts for the wind-prostrate growth of trees at Dongara and — regionally far more significant — the accentuation of drought along the west coast.

An essay on aperiodic May rains (Gentilli 1972b) stressed the potentially great ecological implications of such rains; it was followed by a paper studying a rainfall storm of similar origin (Gentilli 1973) and by an analysis and explanation of some of these 'epitropical westerly jet advected storms' (Gentilli 1979), although it was already suspected that the term 'storms' could not apply to the many cases in which there was a simple northwesterly flow without the clockwise bend which causes more uplift and heavier precipitation. A minute description of the phenomenon, called simply 'the Australian cloud band', appeared soon afterwards (Downey *et al.* 1981), followed by two thorough analytical and climatological studies (Tapp and Barrell 1984, and Kuhnel 1990). Satellite imagery is now regularly used in weather forecasting, and some TV weather bulletins show daily images of cloud patterns, among which these epitropical bands figure quite prominently.

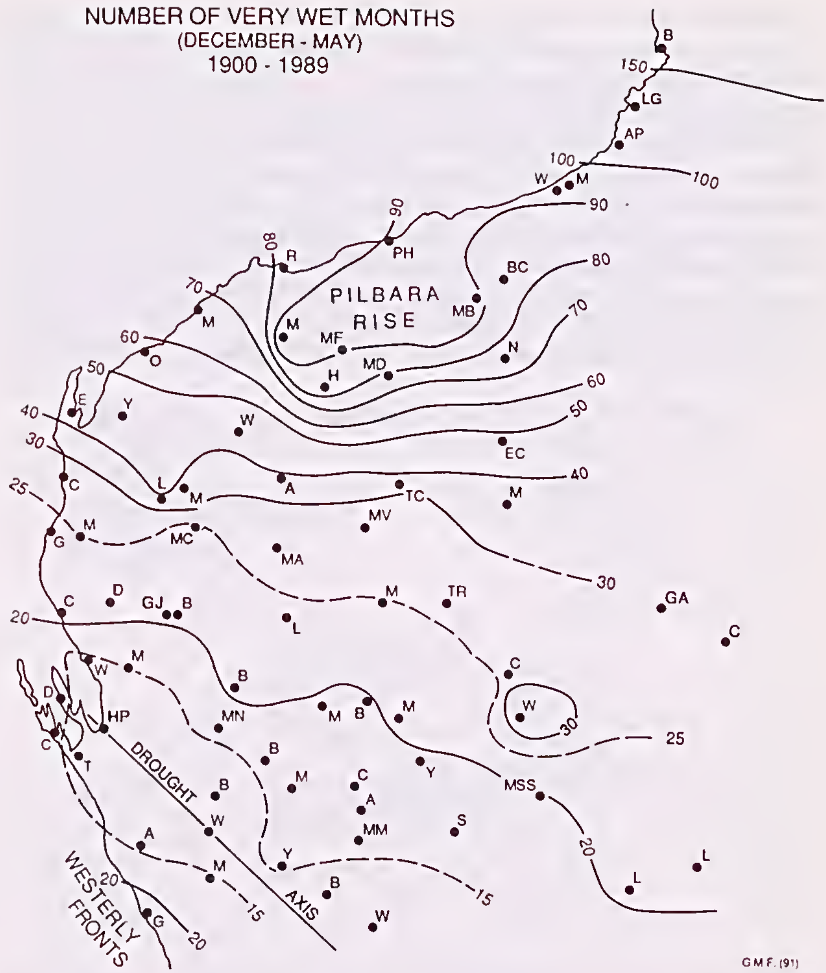

Figure 2. Number of very wet months, December to May semesters 1900-1989.

HISTORICAL REVIEW

Because of the sporadic occurrence of such heavy rains any short-term review could be badly affected by chance. On the other hand most rainfall records are of fairly recent date, and some stations have interrupted or truncated records. Where possible all records from 1900 to 1989 have been used in the preparation of the maps presented here.

Over this ninety-year span the total number of months in the December-May semester with 100 mm or more per month ranged from 165 at Broome (at the northern limit) to 11 at Billabalong and Wandina in the Murchison (Figure 2). The 'drought axis' for very wet months runs NW-SE from Shark Bay. The total drought axis of the average rainfall map also begins at Shark Bay but (because of winter westerly winds) runs WNW-ESE, passing well to the north of Kalgoorlie, eventually to reach the Nullarbor Plain. The diverging of the two rainfall axes means that at Wiluna the number of heavy December-May showers is about double that of Mount Magnet, which still has a slightly greater median rainfall.

These heavy falls will now be examined month by month. Figure 3 shows the very wet months of December, only known to have occurred north of the Onslow-Laverton diagonal. They are due to a broader band of monsoonal flow reaching a little south of Broome, or, rarely, to early tropical cyclones. In this latter case, the shape of the land surface becomes a significant factor, as shown by the increased frequencies at Nullagine, Marble Bar and Millstream,

Figure 3. Number of very wet December months, 1900-1989.

whereas Mulga Downs, in a sheltered part of the Fortescue Valley, recorded only one very wet December in 90 years.

In January (Figure 4) the monsoonal flow is better established. Tropical cyclones are less uncommon, and follow more broadly curved tracks which make them cross the coast somewhere between Port Hedland and Onslow. The highest frequency of wet Januaries (outside the monsoon-affected Kimberleys) is found on the NW-facing slopes and valleys of the Pilbara: Hamersley, Marble Bar, Mulga Downs, Bamboo Creek, with 25 or more wet Januaries each in the 90 years. Localities downwind, no matter at what altitude, see such events as a rarity: 6 times at Ethel Creek, 5 times at Mundiwindi, 4 times at Three Rivers. Inland from Onslow, in the absence of steep

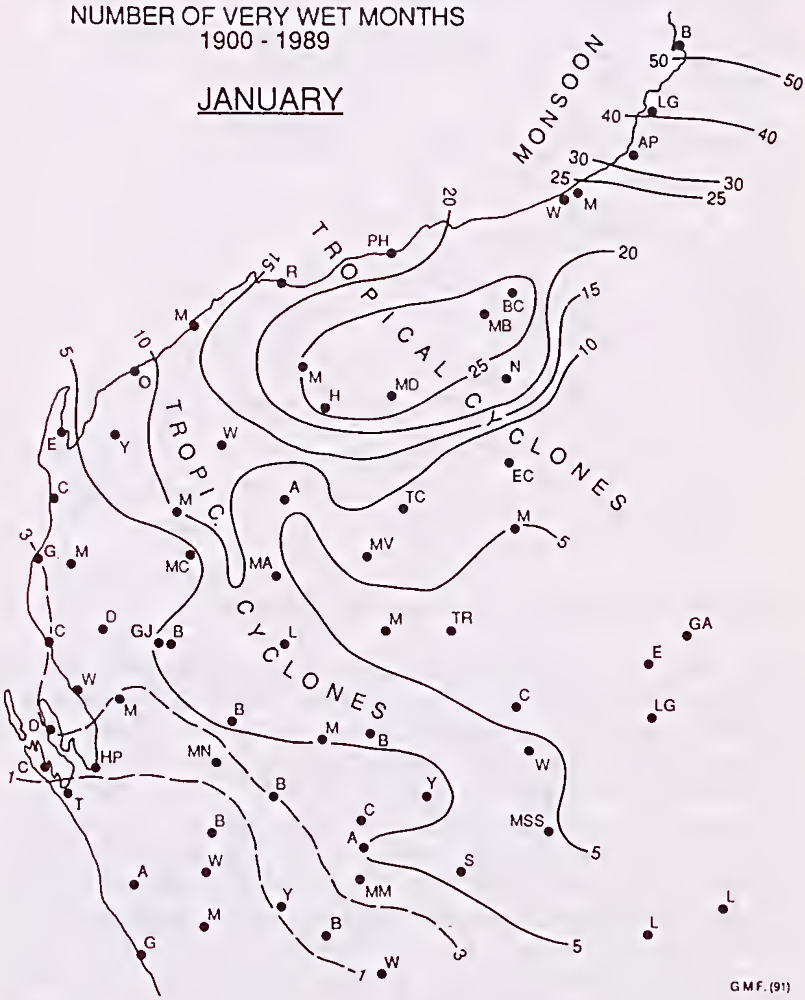

Figure 4. Number of very wet January months, 1900-1989.

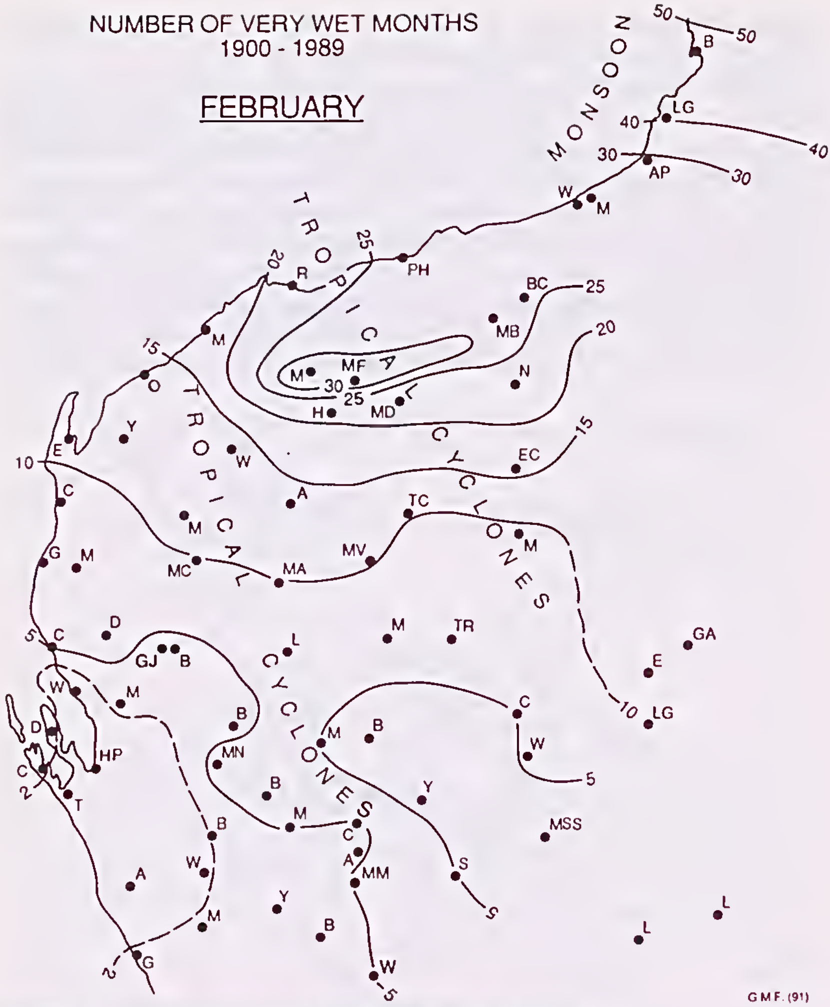

Figure 5. Number of very wet February months, 1900-1989.

slopes, rain from cyclones is carried much further, with Leonora and Laverton, for instance, over twice as distant downwind from the coast as Mundiwindi, having about the same number of very wet Januaries in the same 90 years [the Laverton record is incomplete and one can only estimate the total].

The pattern for February (Figure 5) is very similar to the January one, except for the fact that cyclonic tracks, nudged by persistent easterlies, describe a slightly wider curve around the coast. Heavy falls occur not only on the windward side of the highlands but also around them to the south: Ethel Creek had 17 very wet Februaries in the 90 years, Mundiwindi and Three Rivers 7 each. The belt of lowest frequencies, which passed north of Wiluna in January, crosses south of there in February. By March (Figure 6) it runs still further south and curves through Mount Magnet. Cyclones are less frequent and their tracks are more irregular.

Thus during the main cyclone season (December-March) over 90 years, Mount Magnet registered 11 occasions with over 100 mm of rain in one month, Sandstone and Leonora 14 each — in a totally different category from the 85 similar occasions at Millstream, 75 at Hamersley or 70 at Nullagine.

By comparison, heavy rains in April and May are rare (Figures 7 and 8). In May, epitropical cloud bands carried by the 'awakened' subtropical jet stream are the main cause, as may be indicated by the slightly clockwise alignment of the frequency lines (tropical cyclones tend to follow slightly anticlockwise tracks, cf. Figures 4-6). The effect of highlands is negligible; the modest higher frequencies

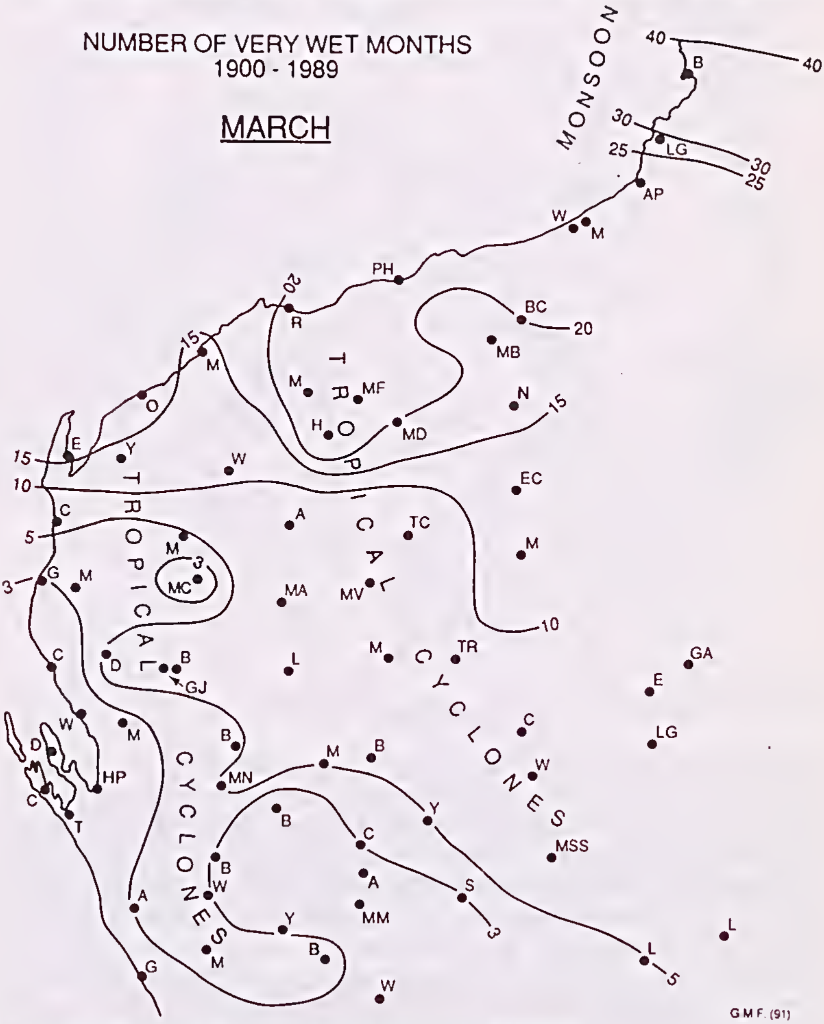

Figure 6. Number of very wet March months, 1900-1989.

Figure 7. Number of very wet April months, 1900-1989.

are found on the coast, and might derive more from increased thermal contrast between the cooling land and the still-warm sea. On the other hand, penetration inland is rather effective because of the greater height at which these cloud systems travel. Leonora and Laverton, for instance, experienced very wet April or May months 6, and 5 or 6, times respectively in the 90 years, against 20 times at Mardie, 17 at Roebourne, 16 at both Onslow and Port Hedland. The amount of rain brought by these weather systems may be far less than is brought by tropical cyclones, but water will persist on the ground longer than in summer because of lower temperatures and

Figure 8. Number of very wet May months, 1900-1989.

less evaporation. By June (Figure 9) the average point of impact had moved westwards some 300 km, towards Exmouth.

SOME RECENT CLIMATIC FLUCTUATIONS

The rarity of the climatic events studied above precludes any

Figure 9. Number of very wet June months, 1900-1989.

normal application of precise statistical methods. They simply must be taken as they happen to come.

A comparison between the 45-year periods 1900-44 and 1945-89 was almost pointless because the two periods were too long, thus hiding some very interesting shorter-term fluctuations. Comparisons between earlier periods had already been made (Gentilli 1952a and 1971 p. 205) and so it was opted for a 1900-29 and 1960-89 comparison, i.e. between the earliest and latest 'normal' (*i.e.*, in climatological convention, 30-year) periods of this century available so far.

The overall comparison (Figure 10) shows a noticeable recent increase in the number of very wet months, particularly at Millstream, Hamersley and Marble Bar. This, together with the decrease towards the west coast from Exmouth to Shark Bay, may be seen as due to an increased frequency of tropical cyclones striking

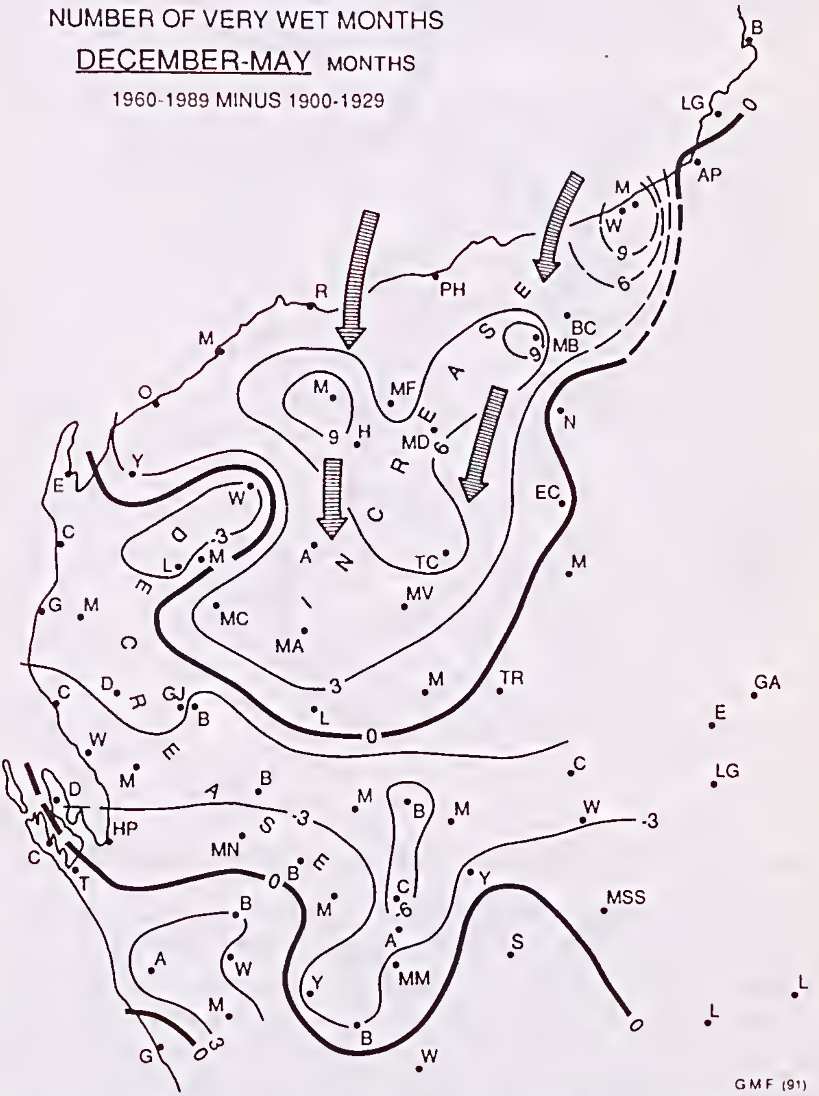

Figure 10. Number of very wet December to May months, 1960-1989 minus 1900-1929.

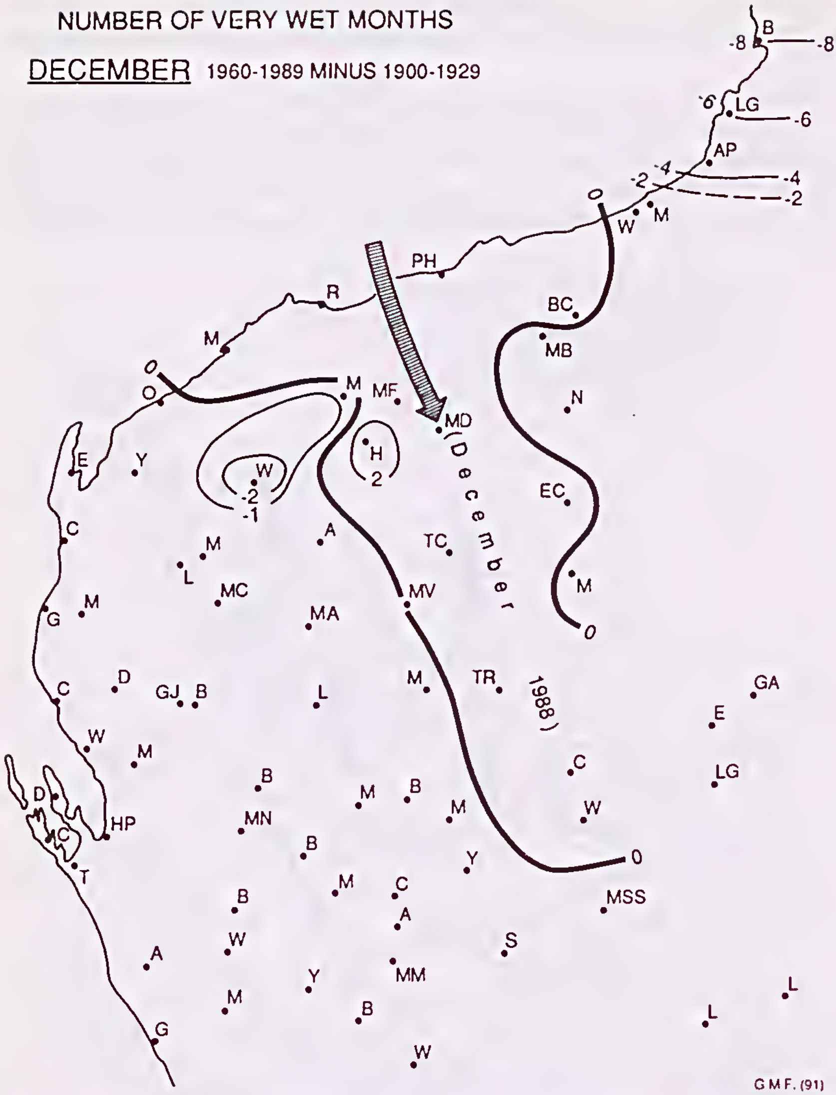

Figure 11. Number of very wet December months, 1960-1989 minus 1900-1929.

from the north-east. The main areas to benefit from this increase are the Pilbara and the adjoining part of the Northwest Division.

A breakdown by shorter 'seasons' reveals more. The December pattern is hardly different in the two 30-year periods (Figure 11) except for a marked decrease of frequencies in the monsoon area. The slight increase in the Pilbara and interior is due to one cyclone in December 1988; Hamersley benefited but Millstream happened to be slightly 'shadowed' and registered good rains, but less than the 100-mm threshold.

After separate examination it was deemed useful to combine the cyclones of January and February (Figure 12). The pattern of notable increases in the number of very wet months peaks at Millstream and Mount Florence and reaches north-eastwards to Marble Bar and probably Bamboo Creek. Frequencies decline rapidly south of the Pilbara highlands, but the prevalent south-eastward track of the recurved cyclones stands out very clearly through the central Northwest Division. Hardly any change is seen from Exmouth to Shark Bay and beyond.

The frequencies of very wet months in March and April of the two 30-year periods were mapped, but did not reveal any significant long-term change.

Figure 12. Number of very wet January and February months, 1960-1989 minus 1900-1929.

Figure 13. Number of very wet May months, 1960-1989.

May (Figure 13) was of particular interest because the epitropical northwesterly flow is the main source of most of its heavy rains. There was a slight recent increase in the number of very wet months south-eastwards from Mardie inland, and on the coast between Port Hedland and Wallal, to the advantage of much of the Pilbara-Northwest Region, but this was more then offset by a clear decrease from Shark Bay inland to most of the upper Murchison basin. There was a very slight increase along the coast towards the agricultural districts, possibly due to an increased (earlier?) frequency of mid-latitude depressions further south.

ACKNOWLEDGEMENTS

Climatic data were obtained from microfiches made available by the Bureau of Meteorology. Thanks are due to Guy Foster, who skilfully and patiently put my maps into fair copy.

REFERENCES

AUSTRALIAN WATER RESOURCES COUNCIL, 1975. *Review of Australian Water Resources 1975.* Australian Government Publishing Service, Canberra.

BUREAU OF METEOROLOGY, 1968. Tropical cyclones in the northern Australian regions for 1964-65 season. *Meteorol. Summary* [n.n.].

CLARKE E.deC., 1926. Natural regions of Western Australia. *J.Roy.Soc.W.Aust.* 12:117-132.

DOWNEY W.K., TSUCHIYA T. and SCHREINER A.J., 1981. Some aspects of a northwestern Australian cloudband. *Aust. Meteor. Mag.* 29:99-113.

GENTILLI J., 1948. Bioclimatic controls in Western Australia. *W.A. Naturalist* 1:81-84, 104-107, 120-126.

GENTILLI J., 1951. Bioclimatic changes in Western Australia. *West. Aust. Nat* 2:175-184.

GENTILLI J., 1952a. Present climatic fluctuations in Western Australia. *West. Aust. Nat* 3:155-165.

GENTILLI J., 1952b. Seasonal river regimes in Australia. *Proceed. XVII Congr.Internat. Geog.Union*, Washington.

GENTILLI J., 1956. Tropical cyclones as bioclimatic activators. *W.A. Naturalist* 5:82-86, 107-117, 131-138.

GENTILLI J., ed., 1971. *Climates of Australia and New Zealand.* Vol. 13 of *World Survey of Climatology.* Elsevier, Amsterdam.

GENTILLI J., 1972a. Thermal anomalies in the Eastern Indian Ocean. *Nature Phys. Sci.* 238:93-95.

GENTILLI J., 1972b. Aperiodic starting rains in tropical Western Australia. *West. Aust. Nat* 12:89-93.

GENTILLI, J., 1972c. *Australian Climate Patterns.* Nelson, Melbourne.

GENTILLI J., 1973. Epitropical climatology of the subtropical jet stream. *Bonn.Meteor.Abh.* 17 *(Klimatologische Forschung, Flohn Festschrift)*: 17:137-165.

GENTILLI J., 1979. Epitropical westerly jet advected storms. *Qld GeogrJ.*, 3rd Ser., 5:1-20.

GENTILLI J., 1991. Homologous peri-oceanic west coast climates in the southern hemisphere. *J.Roy.Soc.W.Aust.* 74:15-33.

KUHNEL I., 1990. Tropical-extratropical cloudbands in the Australian region. *Int. J. Climatol.* 10:341-364.

MATSUMOTO J., 1989. The seasonal changes of tropical cloud distribution as revealed from 5-day mean outgoing longwave radiation. *Jap.Progress in Climatol.*, Dec. 1989, pp. 18-34.

MILTON D.J., 1978. The rainfall from tropical cyclones in Western Australia. *Geowest* No. 13. RAMAGE C.S., 1984. Climate of the Indian Ocean north of 35° S. In: H. van Loon, ed., *Climates of the Oceans.* Elsevier, Amsterdam.

TAPP R.G. and BARRELL S.L., 1984. The North-West Australian cloud band: climatology, characteristics and factors associated with development. *J. Climatol.* 4:411-424.

VAN DE GRAAFF W.J.E., CROWE R.W.A., BUNTING J.A. and JACKSON M.J., 1977. Relict early Cainozoic drainages in arid Western Australia. *Zeitschr. für Geomorph.* 21:379-400.

WYRWOLL K.H., MCKENZIE N.L., PEDERSEN B.J., TAPLEY I.J., 1986. The Great Sandy Desertof Northwestern Australia: the last 7000 years. *Search* 17(7-9):208-210.